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FLUVIAL AND RIPARIAN ENVIRONMENTS OF THE MIDDLE RIO PUERCO, NEW MEXICO: A REVIEW OF HOLOCENE SEDIMENTATION HISTORY

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Fluvial and Riparian Environments of the Middle Rio Puerco, New Mexico: A Review of Holocene Sedimentation History

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The large watershed of the Rio Puerco has been of long, continual interest to range managers and soil scientists because of the deterioration of the rangelands and severe erosion and gullying that have occurred since the 1880s (Scholl and Aldon, 1988; Phippen and Wohl, 2003).

Historic Erosion

In an early assessment of gullying history and search for the origin and cause of the erosion, Kirk Bryan (1928, p. 280) observed that the destructive arroyo cutting occurred between 1885 and 1890, immediately after the area was fully stocked with cattle, a pattern that applied as well throughout the southwest (Bryan, 1925). Bryan concluded that overgrazing led directly to decreases in vegetative cover that in turn led to increased runoff and increased erosive power of streams.

In the same paper, however, Bryan introduced an element of uncertainty that led to the confusion of a generation of later investigators. Before working along the Rio Puerco, Bryan had just completed his geomorphic study of the canyon fill at Chaco Canyon where he documented the locally famous post-Bonito channel, a prehistoric arroyo that began to erode about 1000 AD (Bryan, 1954, Hall, 1977). Bryan (1928) reasoned that, since the post-Bonito arroyo formed long before cattle were introduced and was therefore related to climatic factors, the 1885-1890 arroyo must also have a climatic cause. Bryan, as well as later investigators, overlooked the important fact that the historic arroyos are a magnitude larger than the 1000 AD counterpart and that the twentieth century arroyos extend up tributary valleys in drainages that were not dissected by 1000 AD arroyos. Furthermore, analyses of weather and tree-ring records indicate that the period 1885-1890 was not significantly different from that of earlier times when arroyo cutting was not occurring. While weather and climate are certainly factors in all surface processes, Bryan's initial conclusion that overgrazing is the prime cause of arroyo cutting that began in the 1880s is compelling.

Historic Inset Terrace Fill

Nearly all arroyos in the southwest include one, and in some cases two, inset terraces of historic age. A precise, accurate age of the fill deposits coupled with local weather records and stream discharge data should yield insights on the circumstances of fluvial

aggradation versus nonaggradation. Thus far, this data set has not been generated in the southwest.

A single inner fill terrace characterizes the Rio Puerco drainage. The Rio Puerco arroyo fill includes both point bar sands and oxbow slow-water silty clays. The deposition of an inner fill terrace occurred in all older tributary arroyos to the Rio Puerco as well. The fill terrace of the tributaries is evidently graded to the fill terrace of the Rio Puerco arroyo and both were likely deposited at the same time. Establishing a chronology of the deposition of the fill terrace would lead to important information of basin-wide erosion and sedimentation.

An attempt to establish a chronology of Rio Puerco arroyo fill deposits using radiometric isotopes cesium-137 and lead-210 was partially successful (Popp et al., 1988). In the lower Puerco, the upper 300 cm of clayey oxbow sediment was found to contain cesium-137 (Fig. 3). Cesium-137 is a product of atmospheric testing of atomic weapons resulting in a worldwide presence of the radioisotope in deposits that have accumulated since 1954. Thus, the identification of cesium-137 in alluvial fill deposits indicates that the sediment accumulated post-1954. Lead-210 is a product of the radiogenic decay of radon gas and is found naturally in clayey deposits, although its short half-life restricts its usefulness for age dating to the past 150 years. Nevertheless, lead-210 analysis has the potential to identify specific ages of sediment, unlike the relative ages (pre-1954, post-1954) of cesium-137. Unfortunately, in this study, background lead-210 was too high to establish a chronology for the arroyo fill deposits.

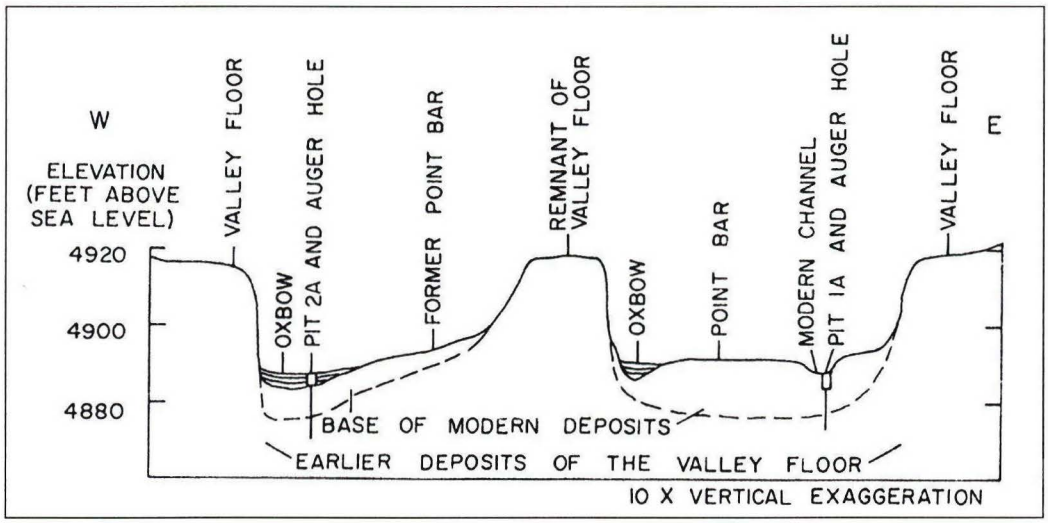

Fig. 1. Cross-section of Rio Puerco arroyo west of Belen, Valencia Co., New Mexico (from Popp et al., 1988, p. 264); presence of radiometric cesium-137 to depth of 300 cm in pit 2 indicates that that sediment accumulated since 1950 (cesium-137 is a product of atmospheric testing of atomic weapons); lead-210 dating was not feasible due to high background lead-210.

Fig. 2. Extensive inner fill deposits of post-1890 age, Middle Rio Puerco.

Radiocarbon dating is of limited usefulness in trying to establish a chronology for the post-1890 sedimentation of the inner fill deposits. Recycled charcoal from older sediments, resulting in a spurious old age, is a continual field problem to be avoided. Charcoal from *in situ* brush fires can provided a general age, but unfortunate natural increases in atmospheric content of carbon-14 during the past 400 years result in less-precise calendar ages. A radiocarbon age of 150 ± 40 ^{14}C yr BP, for example, could correspond to any calendar age between 1640 and 1940 AD.

Prehistoric Floodplain Sedimentation

Much of the literature on fluvial geomorphology in the southwest has focused on channels; only a few investigators have studied the stratigraphy, sedimentation, and geochronology of floodplain and valley fill deposits.

The high arroyo walls of the Rio Puerco expose a complex sequence of sand and clay floodplain deposits with numerous minor and some major channel fills (Fig. 3). While challenging, it is possible to map and correlate the alluvial units (Love et al., 1982).

Two of the prominent features of the 11 meters or more of alluvium exposed in Rio Puerco arroyo walls are the contrasting units of sand and clay and the large paleochannel fills. The sands are largely derived from local tributaries, while the clay-rich sediments are derived from upstream areas of the Rio Puerco watershed. Close inspection of the paleo-floodplain sediments shows that the thick clay beds are composed of thin-bedded fine silty sands and clay and that the sand units often incorporate thin clay beds. The large paleochannels are difficult to sort out: they may represent one or more than one meandering channel that is intersected and exposed in the modern arroyo walls.

Clearly, a firm chronology of the alluvial deposits and channel fills is vital to piecing together a coherent geomorphic history of the Rio Puerco. Two sources of chronologic information are radiocarbon dating and archaeology. The radiocarbon dating of organic matter in clays does not work because of the presence of Cretaceous and Tertiary lignite and carbonaceous rocks in the Rio Puerco basin; organic particles of Cretaceous or Tertiary age that are mixed with Holocene detritus will give erroneously old ages for Holocene sediments. Radiocarbon ages of isolated pieces of charcoal in alluvium are also

questionable because the charcoal may be recycled from older deposits and give spuriously old ages. Thus, the investigator must find *in situ* charcoal from a natural fire or a buried archaeological site.

Using the presence of an archaeological site to provide ages of geological deposits can be problematic. Archaeological sites and features within a site are intrusive into older sediments and cannot be applied directly to the age of the sediments; the geological deposits are *older* than the age of the archaeology. If the site is completely buried and capped by post-site sediments, then the age of the site will provide the age of the horizon between pre-site and post-site deposits. Recycled artifacts, such as pottery, fire-cracked stones, and flint tools, are common in some areas where prehistoric activities were concentrated. However, while artifacts may occur abundantly in sediments, the investigator must keep in mind that geological deposits are *younger* than the age of the recycled artifacts.

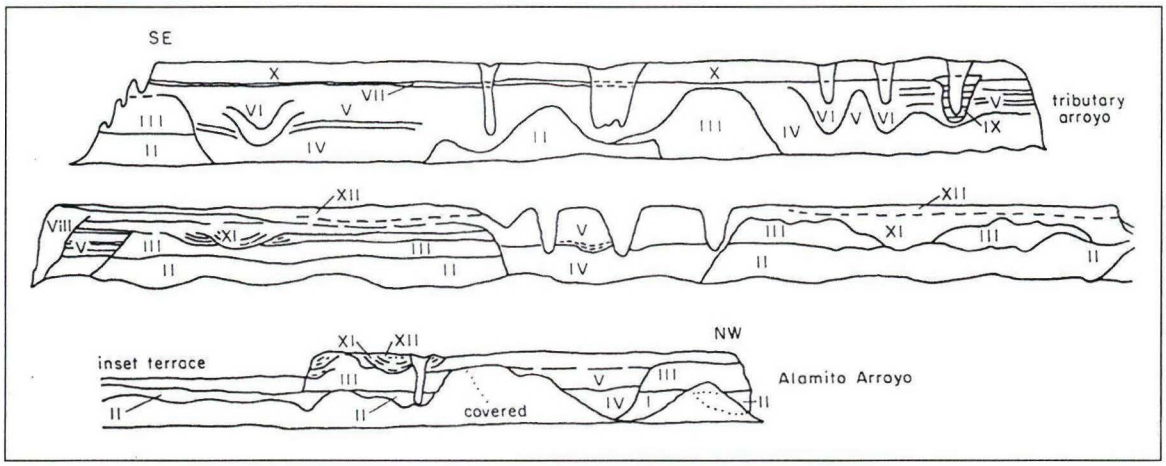

Fig. 3. Stratigraphy of lower Rio Puerco alluvium exposed in arroyo wall along 1.4 kilometers south of the mouth of Arroyo Alamito, Socorro Co., NM; maximum height of arroyo wall about 11 meters (from Love et al., 1982, p. 42); alluvial unit I = local-derived red-brown clayey sand and Puerco-derived dark laminated clay; II = laminated gray and red-brown clays that extend continuously at the base of the floodplain for more than 1 km; III = interbedded sand, silt, and clay from local and Puerco sources; IV = one or more Puerco channels; V = local or Puerco-derived sand and laminated clay that may be a separate channel or a facies change of IV channels; VI = narrow sandy channels that cut earlier sandy channels; VII = continuous layer of red silt and clay; VIII = large tributary channel filled with reworked sand and clay aggregates; IX = small tributary channel filled with locally-derived sediments; X = red-brown clayey sand with a weak soil and incorporating Basketmaker III sites; XI = clayey sediment fill of a series of shallow meandering channels; XII = massive gray-brown clay that overlies channel and floodplain deposits (alluvial unit descriptions paraphrased from Love et al., 1982, p. 43, 49); none of the alluvial units were dated except for unit X that incorporates Basketmaker III sites.

Tapia Arroyo

Owing to the complexity of the paleo-floodplain stratigraphy as exposed in arroyo walls along the Rio Puerco, coupled with the difficulty of closely inspecting the 11-meter high exposures, it was proposed to analyze the alluvial geology of Tapia Arroyo, a major tributary of the middle Rio Puerco. It was reasoned that the alluvial stratigraphy of the tributary should be graded to and in synchronicity with fluvial deposition and erosion of the master stream. Thus, the alluvial chronology of Tapia Arroyo should match major fluvial events of the Rio Puerco.

While the geochronology of the alluvial sequence is in analysis, the sedimentation of the alluvium shows alternating depositional episodes of overbank muds, coarse sands, and minor erosional events that include two major periods of channel cutting and filling. Six alluvial units, the base of each marked by an erosional unconformity, are defined from the 11-meter thick valley fill exposed in arroyo walls (Table 1; Fig. 4). The lower-most unit F consists of coarse cross-bedded sands and thin clay beds; unit E is a massive yellowish brown clay with some thin bedding and formed during the first period of broad overbank sedimentation in the valley; unit D is a massive medium brown hard clay that also formed by slow overbank sedimentation although a lower zone of gravely sand marks a short-duration episode of valley-wide flooding and scouring and coarse sediment deposition;

Table 1. Stratigraphy and sedimentation of Tapia Arroyo, locality 1A and 1B, tributary to middle Rio Puerco; measured by S. A. Hall, 2004; photograph of loc. 1B in Fig 4.

UNIT	DESCRIPTION
A	0 to 90-170 cm depth, light brown, fine quartz sand, some clay beds in lower part of unit, secondary carbonates; basal contact is an erosional unconformity that may correspond to channel with axial basalt gravels exposed downstream
B	170 to 390-410 cm depth, medium brown, clay, silty with very fine sand, massive, hard; massive clay bed split by fine sand zone; upstream the clay bed thins and grades into sandy facies; lower 30 cm is a gravely sand with small crossbeds; sharp lower boundary is a minor erosional unconformity
C	410 to 530 cm depth, light brown, fine sand, clayey, small crossbeds, massive where not crossbeds, thin clay zone in lower 40 cm; base of unit is erosional unconformity that corresponds to channel cut into unit D upstream from loc. 1a; channel extends 210 cm below the base of unit C and is filled with gravels and cross-bedded sand
D	530 to 770 cm depth, medium brown, clay, massive, hard, occas. fine laminar bedding, small clay balls; weak A horizon soil at top of unit D; lower 20-25 cm is a coarse-medium sand, poorly sorted, crossbedded, with small gravels of basalt and sandstone and occas. clay balls; this lower gravely sand extends laterally some distance; the top of the basal sandy gravel zone is a minor erosional unconformity overlain by massive clay-fine sand-clay that dominates unit D; the sharp basal contact of unit D is a minor erosional unconformity
E	770 to 880-890 cm depth, light yellowish brown, clay, silty, massive, hard, carbonate filaments, sharp basal contact is minor erosional unconformity
F	890 to 1060+ cm depth, yellowish brown, banded clays and sand in upper half of unit, coarse crossbedded sand in lower half of exposed portion of unit; the lower 250 cm of arroyo wall above the modern channel (2004) is concealed by slumped sediments

Fig. 4. Tapia Arroyo, loc. 1B, with stratigraphic units; 1-meter scale on right; section characterized by alternating clay and sand deposition during the past 5000 years; each unit is bounded by a minor unconformity representing a shift in depositional regimes; a major erosional unconformity occurs at D/C boundary and is marked by channel erosion into unit D and the filling of the channel by unit C; the weak A horizon soil at the top of unit D represents a short-duration slowing of floodplain sedimentation and stability during the trenching and filling of the D/C channel (photograph by S. A. Hall, June 10, 2004)

unit C consists largely of cross-bedded sand with some clays and represents a channel-fill deposit that extends into unit D; while valley runoff and sedimentation was confined to the D/C channel a weak A horizon soil formed on the stable surface of unit D; upon filling of the D/C channel, sandy sediments were once again deposited on the floodplain, burying the A horizon soil and unit D; unit B is a brown massive hard clay that represents a return to slow, overbank deposition of fine sediments on the valley floor; unit A is a gravely sand that is the last canyon fill sediments subsequent to the filling of a deep channel with axial basalt gravels (Fig. 4). The cutting of the B/A channel is a major shift in valley sedimentation following the accumulation of the thick sequence of overbank clays and fine sand of unit B. The thick clay beds have some secondary carbonate filaments. The clays generally exhibit thin bedding and thin clay drapes and other

Fig. 5. Paleo-arroyo fill, Tapia Arroyo, downstream from loc. 1 (Fig. 4); coarser basalt gravels accumulated and preserved in the thalweg of the paleochannel, described by Shepherd (1978); the paleochannel may have downcut after the deposition of unit B and subsequently filled with sediment of unit A, thus is a B/A channel; the channel may correlate with Nials' channel cutting/filling 1000-1200 AD and the post-Bonito channel at Chaco Canyon cut ca. 1000 AD

primary micro-features that can be traced one meter or more laterally. The clay beds also include occasional beds of fine sand less than 10 cm thick. None of the alluvial sediments exhibit iron staining or other indicators of high groundwater. Overbank clays represent 60% of the vertical sequence at Tapia Arroyo, and it is speculated that the slowly accumulating overbank clays also represent 90% of the time preserved in these deposits. The remainder of the geologic record is marked by channel cutting and rapid aggradation of channels and infilling of the valley floor by fast-water transported sediments. Once an accurate chronology is established, a parallel history should be found in the Rio Puerco.

Correlation of Tapia Arroyo Alluvial Stratigraphy

Correlation of alluvial sequences are generally made possible due to synchronicity of episodes of channel trenching that in turn are caused by subcontinent changes in climate and accompanying changes in local vegetative ground cover and surface hydrology. Local details of valley sedimentation are generally too complex and diverse to apply as

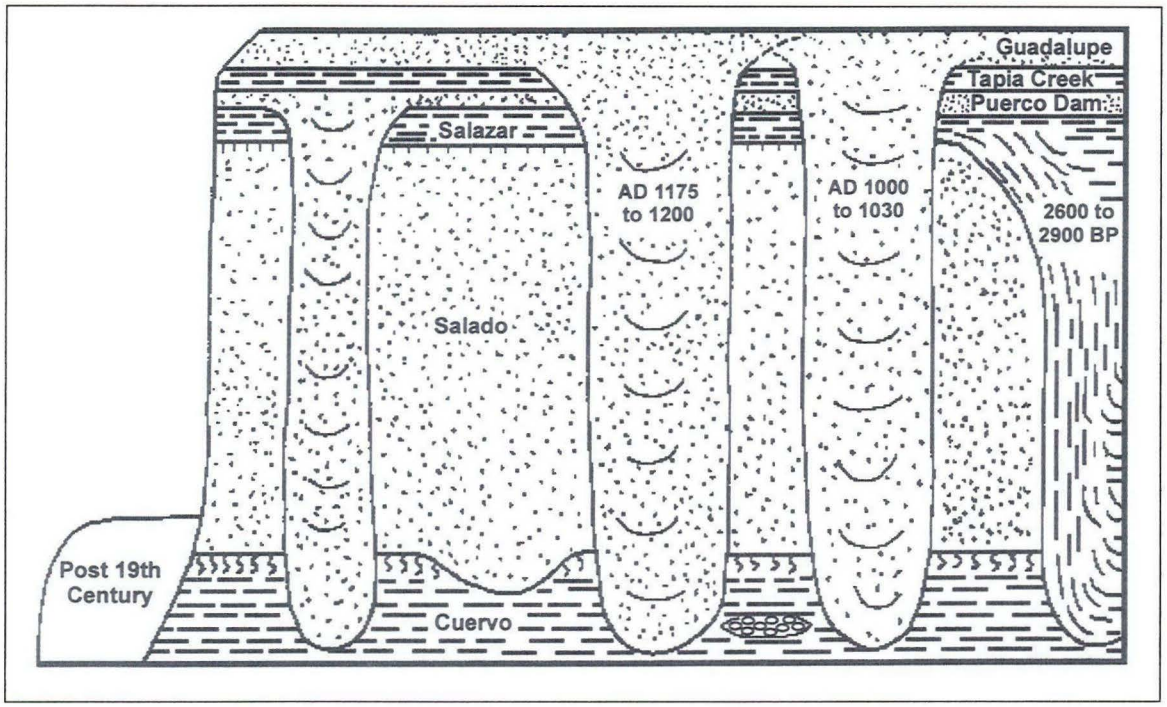

Fig. 6. Summary diagram of alluvial stratigraphy along Middle Rio Puerco, Sandoval County, New Mexico (from Nials, 2003, p. 32); stratigraphic sections with accompanying radiocarbon and archaeological ages were not presented.

criteria for correlation, although at the same time these local details can provide valuable information on stream behavior that may in turn lead to regional patterns of valley sedimentation.

The alluvial sequence documented in Tapia Arroyo does not appear to correspond to the alluvial history of the same area of the middle Rio Puerco presented by Nials (2003) (Fig. 6). The alluvial units are dissimilar, Tapia dominated by clays and Nials' sequence dominated by sand. The Tapia record indicates two paleo-channel fills while Nials observed four.

The only other radiocarbon-dated alluvial sequence from the region for comparison is from Chaco Canyon that, during the past 7000 ^{14}C years, shows two periods of channel cutting, the first beginning at 2400 ^{14}C yr BP and the last beginning at 1000 ^{14}C yr BP (Hall, 1977). The last one is the post-Bonito channel that formed while Puebloans were living at Chaco Canyon. Each episode of channel trenching was rapid, and filling of the trenches probably occurred within 200 or 300 years of their initiation. The channel trenching documented by Nials between 1000 and 1200 AD is probably the same as that at Chaco. Indeed, subcontinent-wide channel trenching began throughout the plains and southwest about 1000 AD (Hall, 1990).

Summary
Alluvial sediments exposed in Tapia Arroyo show that the entire record, likely spanning the past 5000 years, is dominated by slow-water overbank sedimentation of clays and fine sands. It is unlikely that an arroyo-like channel existed during this time, and the canyon filled by slow aggradation as runoff water spread out over the canyon floor, creating a riparian environment that differed markedly from that of today. Twice the history of slow aggradation was interrupted by entrenchment. After the first period of down cutting, perhaps correlating with the Chaco Canyon episode of channel cutting about 2400 ^{14}C yr BP, the canyon returned to its previous behavior of slow sedimentation. After the second period of down cutting, however, perhaps correlating with the regional period of channel erosion about 1000 AD, Tapia Canyon never recovered. The quiet slow sedimentation and the riparian canyon habitats that characterized previous millennia were lost. During the past 1000 years, fluvial sedimentation apparently did not occur at Tapia Canyon, or alternatively the deposits have been lost due to erosion of the modern arroyo. The modern arroyo at Tapia likely formed by headward cutting from the Rio Puerco after 1890.

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